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Short communication

Performance characterization of influent and effluent treatment systems: A case study at Craig Brook National Fish Hatchery

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Abstract

This study characterizes the performance of influent and effluent disinfection systems at Craig Brook National Fish Hatchery, a U.S. Fish and Wildlife Service (USFWS) Atlantic salmon *Salmo salar* restoration facility in East Orland, ME. Influent treatment of the hatchery's water supply limits fish exposure to pathogens and protects the hatchery's goal to recover endangered Atlantic salmon. Disinfection treatment of effluent from the hatchery's wild fish receiving building ensures containment of pathogens that could be transferred to the facility with young fish captured from native rivers and protects the downstream hatchery watershed area. Evaluation of the influent treatment system consisted of assessing the effectiveness of the sand filtration and ultraviolet (UV) disinfection equipment, which are used to treat the water supply for the entire hatchery. Evaluation of the effluent treatment system examined the effectiveness of microscreen filtration and UV equipment that are used to disinfect effluent from the hatchery's wild fish-receiving building. Water samples were collected every 2 weeks for a 6-month period. The evaluation of both treatment systems indicates effective solids removal and total heterotrophic bacteria inactivation (2–4 $\log_{10}$ reductions). No disease issues attributable to the hatchery's water supply have occurred during operation of its influent disinfection system, enabling the USFWS continued success with its restoration programs.

Keywords: Microscreen filtration; Sand filtration; UV disinfection; Effluent treatment; Influent treatment

1. Introduction

Craig Brook National Fish Hatchery (NFH) focuses on the restoration of Atlantic salmon *Salmo salar* populations to the rivers of northern New England. The hatchery currently raises Penobscot River Atlantic salmon fry, a restoration program that began in 1871 to replenish diminishing populations resulting from overfishing. In the early 1990s, the hatchery also became a broodstock-holding, egg, and fry production facility for six river-specific, distinct population segments (DPS) of federally listed endangered Atlantic salmon. To facilitate DPS River restoration, Atlantic salmon parr are captured from native rivers and brought to a wild fish receiving building at Craig Brook NFH. The wild fish receiving building has 12 isolation bays, constructed with the intention of segregating two capture-years of each DPS river strain. Under current operation, the wild DPS river salmon are typically only held in the receiving building for 1 year before being transferred to another culture building on station where they are raised into broodstock and used for future spawning and fry production. As a result, the wild fish-receiving building is currently underutilized and has empty bays.

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Two surface water sources are used at the hatchery: Craig Pond and Alamoosook Lake. Craig Pond is located on a hill above the hatchery and provides a gravity-flow water supply through one of two pond intakes. One intake is located approximately 6 m from shore at a shallow depth of 9.8 m to supply warmer water, and the other intake is located approximately 50 m from shore at a deeper depth of 16.8 m for cooler water. Alamoosook Lake is located below the hatchery, and water is pumped to the hatchery from an intake approximately 7 m from shore at a depth of 4.5 m. Four small streams and a spring feed Craig Pond, while Alamoosook Lake receives effluent from the hatchery as well as drainage from several ponds and brooks in the area. The hatchery has a water use agreement with surrounding landowners regarding the amount of water that can be used from Craig Pond. As a result of this agreement, Alamoosook Lake water is generally used for fish culture activities from the end of October to late May.

1.1. Influent treatment at the water treatment building

Fish raised in intensive and semi-intensive culture environments are more susceptible to disease outbreaks when exposed to opportunistic or obligate pathogens. *Aeromonas salmonicida* is present in the Craig Brook NFH watershed area and there are concerns of transferring the bacteria to the hatchery; consequently, surface water supplies are disinfected at the hatchery prior to use. Other hatcheries across the United States similarly disinfect surface water supplies to minimize risks of disease outbreaks. The majority of these hatcheries utilize either ultraviolet (UV) irradiation or ozone disinfection systems with filtration processes prior to disinfection. UV disinfection systems are more commonly encountered to disinfect influent or effluent in aquaculture systems because they are less complex and labor intensive to operate and have lower capital costs compared with ozone disinfection systems (Summerfelt, 2003). However UV disinfection systems are less capable than ozone systems of responding to changes in water quality, such as increased turbidity resulting in decreased UV transmittance, which typically occurs in many surface waters during precipitation and snowmelt events. Summerfelt (2003) provides a comprehensive review and comparison of ozone and UV disinfection technologies used in aquaculture systems.

Filtration before UV treatment results in the absence of particulate matter during UV treatment, assuring that water is effectively treated with UV irradiation and treatment of bacteria is not blocked by particulate matter in the water. Filtration prior to ozonation decreases the risk of transferring pathogens with particulate matter, and reduces the ozone demand of the water. Green Lake NFH (East Orland, ME) operates an influent microscreen filtration and UV disinfection system that was described by Cross and Peterson (1987). The Pittsford NFH (North Chittenden, VT) also operates an influent microscreen filtration and UV disinfection system. Both filtration and disinfection systems were installed after the hatcheries experienced disease problems originating from their respective water supply sources. Lamar NFH (Lamar, PA) utilizes a microscreen filtration and ozone disinfection system to treat influent water to its intensive culture building (Summerfelt et al., in press); Merwin Hatchery (Ariel, WA) also disinfects the majority of its surface water supply with ozone (Cryer, 1992).

The influent disinfection system at Craig Brook consists of sand filtration followed by UV irradiation. Six sand filtration units and five UV units are located in the influent treatment building. Sand filters are 2.75 m in diameter, manufactured by Neptune-Benson Inc. (West Warwick, RI). Each filter has a 15 cm deep gravel base, a sand filter layer 76–91 cm deep, and a 1514 Lpm treatment capacity. Three of the sand filters were installed in 1980 and the remaining three filters were installed in 1991. Filters are operated at a hydraulic loading rate of 255 Lpm/m^2, an incoming pressure of 310 kPa and an outgoing average pressure of 276 kPa. The sand filter units are manually backwashed when the pressure differential between incoming and outgoing water reaches 69 kPa. Filter backwashing generally occurs on a daily basis and requires approximately 11,356–13,249 L of water for each filter, which is approximately 0.5–0.6% of the daily treated flow per filter. During the backwash cycle for a single filter, the hydraulic loading rate on the remaining five filters increases. Sand filter backwash is discharged to the hatchery settling pond, which discharges to Alamoosook Lake; sand filter backwash is not disinfected because it is not used for fish culture and presents no disease risk to the watershed area.

Four of the UV units in the influent treatment building are low pressure/low intensity units manufactured by Ultra Dynamics Corporation (Santa Monica, CA) and installed at Craig Brook NFH in 1980. Each unit has 52 bulbs and a 2271 Lpm treatment capacity. The fifth UV unit is a Wedeco Ideal Horizons (Charlotte, NC) low pressure/high intensity unit that was installed in 2000, and has 60 bulbs and a treatment capacity of

4542 Lpm. The newer Wedeco UV unit is currently used for the majority of hatchery water disinfection, and one of the older units is utilized when the water demands at the hatchery increase above 4542 Lpm. The UV units at Craig Brook NFH were sized to provide a dose of 30,000 μW/(s cm^2) at 90% transmittance at the end of lamp life, providing inactivation of *A. salmonicida*. The lamp output at the end of the lamp service life is commonly used as the design point for UV disinfection systems to ensure that the design dose is achieved over the entire working lifespan of the lamps. Wedemeyer (1996) reported that 5000 μW/(s cm^2) can achieve 99.9% inactivation of *A. salmonicida*, and Bullock and Stuckey (1977) reported that 13,100 μW/(s cm^2) prevented transmission of furunculosis from water that contained *A. salmonicida*. The conservative influent UV design dose for the targeted bacteria at Craig Brook NFH demonstrates the low tolerance of the USFWS for disease problems at its restoration facilities.

1.2. Effluent treatment at the wild fish-receiving building

Although not as common as disinfecting influent water supplies, several facilities such as the Western Fisheries Research Center (Seattle, WA), National Fish Health Research Lab (Leetown, WV), and National Coldwater Marine Aquaculture Center (Franklin, ME) operate effluent disinfection systems to minimize risks of pathogen transmission to surrounding waters. An effluent disinfection system was installed in the wild fish-receiving building at Craig Brook NFH in 2002. Construction of the disinfection system was primarily the result of USFWS concern over the potential impact of infectious salmon anemia (ISA) virus on the endangered Atlantic salmon restoration activities at the hatchery. The ISA virus was detected in commercial salmon net pen operations in Cobscook Bay, Maine, an area through which wild Atlantic salmon broodstock returning to spawn in their native rivers pass. Horizontal and vertical transmission of various diseases including ISA is possible, and young wild Atlantic salmon are captured in the rivers and brought to the wild fish receiving building at Craig Brook NFH to be used for future broodstock. The USFWS installed the effluent disinfection system to prevent the spread of fish pathogens that may have been transported to the facility with the young salmon captured from the wild. Disinfection of receiving building effluent protects the Service's restoration goals by protecting the Lower Penobscot watershed area and prevents disease transmission from the hatchery to Alamoosook Lake and potentially from Alamoosook Lake back into the hatchery.

The receiving building effluent disinfection system was designed to treat 1893 Lpm; 114 Lpm is the approximate water use in each of the 12 receiving building bays and 530 Lpm was included for a planned future program expansion. Effluent disinfection consists of microscreen filtration for gross particle exclusion followed by UV irradiation. Effluent from the rearing areas is collected and filtered for particulates using one of two microscreen drum filters. The microscreen drum filters exclude fish feces, uneaten feed, and other particulate matter from entering the UV units, ensuring effective UV treatment. The microscreen filters have low operational water pressure head requirements and their installation allows for gravity-flow treatment of effluent. The two drum filters, manufactured by PRAqua Supplies Ltd. (Nanaimo, BC), are installed in a parallel-flow configuration with one serving as a redundant filter for maintenance purposes. Each drum filter has 37 μm polyester fabric sieve panels and a design treatment capacity of 2752 Lpm at an effluent solids concentration of 15 mg/L. Drum filter sizing incorporated a safety factor of 1.5 to minimize overwhelming the filter panels during fish tank cleaning flows.

The drum filters have a central, automatic, high-pressure backwash system for filter media cleaning, which operates on-demand as solids accumulate on the filter panels. The backwash water flow, which is approximately 0.2–0.3% of the process flow (Summerfelt et al., 2001), contains waste solids screened from the effluent. Filter backwash is directed to a 7571-L septic tank adjacent to the receiving building, and as the backwash flow enters the septic tank, solids settle to the bottom. Supernatant from the septic tank flows to an adjacent pump sump, and is periodically pumped back to the head of the receiving building effluent treatment system for filtration and disinfection. The supernatant is disinfected to further reduce the potential for pathogen transport from the hatchery since it has come into contact with fish waste. The amount of time the supernatant remains in the pump sump varies depending on the number of drum filter backwash events, which depends on the fish loading in the receiving building. Solids are removed from the septic tank by a local septic hauler.

UV irradiation of effluent in the wild fish-receiving building is accomplished using two Wedeco Ideal Horizons (Charlotte, NC) open-channel type UV units in a parallel flow configuration. The capacity exists to allow one unit to be redundant and off-line while the

entire effluent flow is treated by the other unit. Each unit was sized to provide a dose of 45,000 μW/(s cm^2) at 80% transmittance at the end of lamp life for a maximum design flow of 1893 Lpm. This UV dose for the disinfection system at Craig Brook NFH is a conservative design parameter when compared to reported levels for inactivation of the ISA virus. Torgersen (1998) reported 4000–10,000 μW/(s cm^2) can achieve a loss of ISA virus infectiveness, and Torgersen (1997) reported 25,000 μW/(s cm^2) as the minimum intensity approved for ISA virus disinfection in the influent water supply to hatcheries and smolt farms in Norway. The conservative UV design dose at Craig Brook NFH reflects the priority of the USFWS to protect and enhance fish populations, as well as their low tolerance for potential disease problems at their hatcheries. Manufacturers' operation and maintenance procedures are followed for all effluent treatment equipment in the receiving building.

2. Materials and methods

The study consisted of 12 sampling events, from May to October, 2004. Although the hatchery is in operation year-round, this time period represents the historical period with the highest biomass at the hatchery, which is partially dependent on the number of fish that can be captured yearly from the wild. From May to October, approximately 410 kg of fish (weighed at the end of the study period) were held in the wild fish-receiving building; fish were fed an average of 375 kg of dry pellet feed and 8.5 kg of krill during that time. Alamoosook Lake was the water supply source during the first sampling event and Craig Pond was the water supply source for the hatchery during the remaining 11 sampling events. From May to October, 2004, the influent flowrate to Craig Brook NFH was 4542–5962 Lpm and the influent to the receiving building were 114–227 Lpm, well below the 1893 Lpm design capacity of the effluent disinfection system.

Due to budget constraints, water samples were analyzed by two different environmental chemistry laboratories: Northeast Laboratory Services (NEL) (Waterville, ME) and the U.S. Department of Agriculture's National Center for Cool and Cold Water Aquaculture (NCCCWA) (Leetown, WV). Except for bacteria analyses, water samples collected during a given sampling event were analyzed at one of the two laboratories on alternate sampling events; each laboratory analyzed the full set of water quality parameters once every 4 weeks. Water samples were analyzed for bacteria by NEL every 2 weeks regardless of which lab

Table 1
Methods used for water quality analyses

Water quality parameter	NEL[a]	NCCCWA[b]
Total organic carbon	EPA 415.1	Shimadzu OCA[c]
Dissolved organic carbon	EPA 415.1	Shimadzu OCA[c]
Alkalinity	EPA 310.1	–
Field pH	EPA 150.1	–
Total phosphorous	SM 4500PB; SM 4500PE	–
Soluble phosphorous	SM 4500PB; SM 4500PE	–
Total reactive phosphorous	–	SM 4500PE
Total Kjeldahl nitrogen	EPA 351.3	
Total nitrogen	–	Shimadzu TNMU[d]
Total dissolved nitrogen	–	Shimadzu TNMU[d]
Total ammonia nitrogen	EPA 350.1	Dionex ICS[e]
Nitrate nitrogen	EPA 353.2	–
Total suspended solids	EPA 160.2	SM 2540 D
Volatile suspended solids	–	SM 2540E
Color	EPA 110.2	–
Turbidity	EPA 180.1	–
Heterotrophic bacteria	SM 9215C	–
Total coliform bacteria	SM 9222B	–

Approved EPA methods are indicated with the EPA preface and followed by the specific method number; approved APHA/AWWA/WEF methods are indicated with the SM preface and followed by the specific method number (APHA, 1998).

[a] Northeast Laboratory Services.
[b] U.S. Department of Agriculture's National Center for Cool and Cold Water Aquaculture.
[c] Shimadzu Total Organic Carbon Analyzer Model TOC-V cpn.
[d] Shimadzu Total Nitrogen Measuring Unit Model TNM-1.
[e] Dionex Ion Chromatograph System—Model ICS 90.

analyzed the full set of parameters. A summary of the analyses performed by each laboratory and the methods used is presented in Table 1. In addition to these analyses, the Department of Crop and Soil Science Nutrient Analysis Lab at Cornell University (Ithaca, NY) provided metals analysis using an inductively coupled argon plasma spectrometer and the Freshwater Institute (FWI) environmental chemistry laboratory provided analyses for UV transmittance for all sampling events. UV transmittance was analyzed using a spectrophotometer with Hach Company method 10054; however samples were not filtered prior to measurement.

Sampling events were conducted at 2-week intervals during the 6-month period; a field technician from NEL collected all samples. Samples were collected at seven locations for each sampling event. The sampling locations are described in Table 2 and further illustrated in Fig. 1. Samples were analyzed for solids, bacteria, nutrients, and metals at selected sample locations. The water quality analyses for each sample location were selected to best target the operational and performance characteristics of the treatment equipment being evaluated. Heterotrophic bacteria were used as indicator microbes for *A. salmonicida* bacteria and ISA virus, the fish pathogens of interest at Craig Brook NFH.

Sand filters in the influent treatment building are routinely backwashed, and the hydraulic loading capacity on the remaining filters increases during the backwash cycle of a single filter. Therefore, the sand filters were evaluated under normal operating conditions and also during a backwash condition. Sample location 2 was sampled during normal filtration conditions before backwashing any of the sand filters. Sample 2c was collected at the same location (location 2), but during the backwash cycle of one of the sand filters. The effluent treatment equipment in the receiving building was evaluated under normal operating conditions and also during pumping of the septic tank supernatant to the drum filter inlet. Samples 4a, 5a, and 6a represent normal conditions in the receiving building, and samples 4b, 5b, and 6b were collected during pumping of the effluent sump (3 min after the sump pump was started).

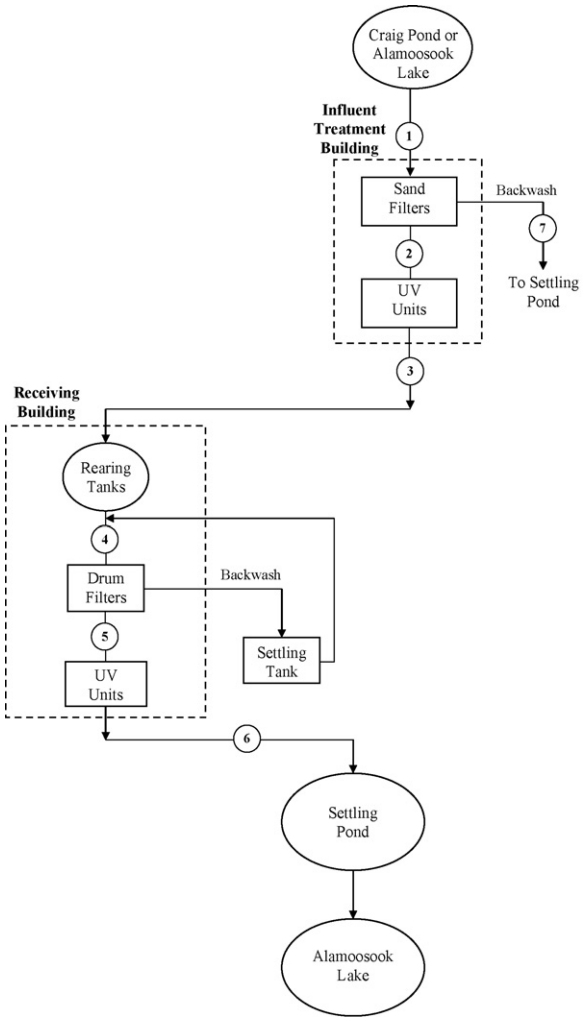

Fig. 1. Sampling locations for water treatment evaluation study at Craig Brook NFH.

Table 2
Description of sampling locations

Sample location number	Sampling location
1	Sampling port on the main process supply line at the influent treatment building
2	Sampling port on the supply line to the UV units in the influent treatment building
3	Sampling port on the effluent line from the UV units in the influent treatment building
4	Sampling port on the influent line to the microscreen drum filter in the receiving building
5	Effluent channel of the microscreen drum filter in the receiving building
6	Effluent channel of the UV unit in the receiving building
7	Manhole (approximately 91 cm deep) adjacent to the influent treatment building to collect backwash from the sand filters in the influent treatment building

Table 3
Average monthly results, ±S.E.; UV transmittance analyses by FWI, all other analyses provided by NEL (May–October)

Water quality parameter	Sample location									
	1	2	2[c]	3	4[a]	4[b]	5[a]	5[b]	6[a]	6[b]	7
Total organic carbon	2.5 ± 0.4 (n = 6)	2.8 ± 0.6 (n = 6)			2.2 ± 0.3 (n = 6)	8.7 ± 1.4 (n = 6)	2.7 ± 0.3 (n = 6)	8.3 ± 1.3 (n = 6)			6.0 ± 1.1 (n = 6)
Dissolved organic carbon	2.0 ± 0.3 (n = 6)	2.4 ± 0.5 (n = 6)			2.2 ± 0.3 (n = 6)	4.1 ± 0.7 (n = 6)	2.8 ± 0.2 (n = 6)	3.9 ± 0.7 (n = 6)			2.5 ± 0.3 (n = 6)
Alkalinity	4.8 ± 0.2 (n = 6)	5.0 ± 0.4 (n = 6)		5.4 ± 0.5 (n = 6)	5.1 ± 0.2 (n = 6)						
Field pH (SU)				6.2 ± 0.1 (n = 5)	6.1 ± 0.1 (n = 5)						
Total phosphorous	<0.01 (n = 6)	<0.01 (n = 6)			0.02 ± 0 (n = 6)	0.97 ± 0.11 (n = 6)	0.02 ± 0 (n = 6)	0.86 ± 0.10 (n = 6)			0.31 ± 0.08 (n = 6)
Soluble phosphorous	<0.01 (n = 6)	<0.01 (n = 6)			0.01 ± 0 (n = 6)	0.58 ± 0.09 (n = 6)	0.01 ± 0 (n = 6)	0.50 ± 0.10 (n = 6)			< 0.01 (n = 6)
Total Kjeldahl nitrogen	<1 (n = 6)	<1 (n = 6)			<1 (n = 6)	4.8 ± 0.8 (n = 6)	<1 (n = 6)	4.5 ± 0.8 (n = 6)			3.0 ± 0.7 (n = 6)
Total ammonia nitrogen	<0.5 (n = 6)	<0.5 (n = 6)			<0.5 (n = 6)	4.1 ± 1.3 (n = 6)	<0.5 (n = 6)	3.5 ± 0.8 (n = 6)			<0.5 (n = 6)
Nitrate nitrogen	<0.5 (n = 5)	<0.5 (n = 5)			<0.5 (n = 6)	<0.5 (n = 6)	<0.5 (n = 6)	<0.5 (n = 6)			<0.5 (n = 6)
Total suspended solids	<1 (n = 6)	<1 (n = 6)			<1 (n = 6)	15 ± 3 (n = 6)	<1 (n = 5)	9 ± 1 (n = 6)			120 ± 40 (n = 6)
Color (APHA)	<5 (n = 5)	7 ± 2 (n = 5)					8 ± 2 (n = 6)	24 ± 3 (n = 6)			
Turbidity (NTU)	<0.5 (n = 5)				<0.5 (n = 6)	6.4 ± 1.9 (n = 6)	<0.5 (n = 5)	4.3 ± 1.0 (n = 6)			
Heterotrophic bacteria (CFU/mL)	67 ± 17 (n = 11)	1180 ± 1080 (n = 11)		9 ± 3 (n = 11)	34,400 ± 30,600 (n = 11)	497,000 ± 317,000 (n = 11)	59,800 ± 35,300 (n = 10)	590,000 ± 428,000 (n = 10)	8 ± 2 (n = 10)	28 ± 15 (n = 10)	57,300 ± 55,300 (n = 11)
Total coliform bacteria (CFU/(100 mL))	50 ± 40 (n = 11)	240 ± 220 (n = 11)		0 ± 0 (n = 11)	60 ± 40 (n = 11)	9200 ± 3100 (n = 11)	3700 ± 2400 (n = 11)	31,000 ± 21,000 (n = 11)	5 ± 5 (n = 11)	<1 (n = 11)	5600 ± 2800 (n = 11)
UV transmittance (%)		92.3 ± 2.1 (n = 12)	94.4 ± 0.2 (n = 11)				93.0 ± 1.2 (n = 12)	82.3 ± 2.3 (n = 12)			

Results in mg/L except where indicated.
[a] Sample collected during normal conditions.
[b] Sample collected during pumping of the septic tank overflow pump sump.
[c] Sample collected just before the backwash cycle for one sand filter was completed.

3. Results and discussion

Average monthly results from analyses provided by NEL, the NCCCWA, and Cornell University Nutrient Analysis Lab are presented in Tables 3–5, respectively. Results from UV transmittance analysis performed by the Freshwater Institute are also presented in Table 3.

3.1. Influent treatment at the water treatment building

From May to October, 2004, the water supplied to Craig Brook NFH was low in total suspended solids (TSS), total phosphorous (TP), total nitrogen (TN), total dissolved nitrogen (TDN), total ammonia nitrogen (TAN), total organic carbon (TOC), dissolved organic carbon (DOC), alkalinity, turbidity, color, and total heterotrophic bacteria (Tables 3 and 4). Dissolved metals concentrations in hatchery water are low and do not cause interference in influent or effluent disinfection processes (Table 5). Metals analyses also indicate good overall water quality for fish culture at the hatchery.

The TSS concentrations measured before and after the sand filters (Table 3) were below the detection limit of 1 mg/L, and did not enable the calculation of TSS removal efficiencies. In contrast, high TSS concentrations were measured in the backwash from the sand filters (120 ± 40 mg/L, n = 6), indicating the sand filters were capturing solids even though mean TSS concentrations entering and leaving the sand filters were below assay detection limits. The concentration of total heterotrophic bacteria increased by just over 1 $\log_{10}$ unit across the sand filter (i.e., from 67 ± 17 to 1180 ± 1080 CFU/mL (Table 3)), which suggests biological activity within the sand bed or the decay of organic matter trapped by the sand filter.

The average UV transmittance of incoming water to the UV units following sand filtration was 92.4% (n = 12), which is above the 90% transmittance design criteria for the influent UV disinfection units. The average UV transmittances of incoming water to the UV units following sand filtration were not considerably different during sand filter backwashing (94.4%, n = 11). This indicates that the increased hydraulic loading rates experienced by the sand filters not being backwashed did not have a negative affect on system performance.

No total coliform bacteria were measured after the UV irradiation units (Table 3). Although 30,000 μW/(s cm^2) was the design dose of the influent units, the in-field dose could not be verified. The heterotrophic bacteria concentration was reduced by just over 2 $\log_{10}$

Table 4
Average monthly results, ±S.E., analyses provided by the NCCCWA (May–October)[f]

Water quality parameter	Sample location						
	1	2	4[a]	4[b]	5[a]	5[b]	7
Dissolved organic carbon[c]	1.60 ± 0.05 (n = 6)	1.47 ± 0.05 (n = 6)	1.66 ± 0.08 (n = 6)	4.50 ± 0.52 (n = 6)	1.68 ± 0.07 (n = 6)	4.67 ± 0.48 (n = 6)	4.99 ± 0.49 (n = 6)
Ammonia nitrogen[d]	0.04 ± 0.01 (n = 6)	0.04 ± 0.02 (n = 6)	0.09 ± 0.01 (n = 6)	3.86 ± 0.99 (n = 6)	0.09 ± 0.01 (n = 6)	3.71 ± 0.90 (n = 6)	0.15 ± 0.03 (n = 6)
Total reactive phosphorous[e]	0.03 ± 0.01 (n = 6)	0.04 ± 0.01 (n = 6)	0.20 ± 0.16 (n = 6)	2.88 ± 0.45 (n = 6)	0.08 ± 0.03 (n = 6)	2.40 ± 0.36 (n = 6)	0.16 ± 0.07 (n = 6)
Total nitrogen[d]	0.13 ± 0.02 (n = 6)	0.14 ± 0.05 (n = 6)	0.29 ± 0.07 (n = 6)	3.46 ± 0.74 (n = 6)	0.19 ± 0.03 (n = 6)	3.20 ± 0.67 (n = 6)	0.30 ± 0.06 (n = 2)
Total dissolved nitrogen[d]	0.11 ± 0.01 (n = 5)	0.12 ± 0.02 (n = 5)	0.21 ± 0.04 (n = 5)	3.20 ± 0.82 (n = 5)	0.24 ± 0.05 (n = 5)	3.02 ± 0.77 (n = 5)	0.40 ± 0.03 (n = 5)
Total organic carbon[c]	1.81 ± 0.06 (n = 6)	1.60 ± 0.05 (n = 6)	2.01 ± 1.9 (n = 6)	7.05 ± 0.85 (n = 6)	1.97 ± 0.12 (n = 6)	6.61 ± 0.61 (n = 6)	
Total suspended solids	7.04 ± 0.76 (n = 6)	6.54 ± 0.23 (n = 6)	9.21 ± 1.99 (n = 6)	29.5 ± 3.21 (n = 6)	6.08 ± 0.56 (n = 6)	21.79 ± 1.24 (n = 6)	231.24 ± 23.69 (n = 6)
Volatile suspended solids	3.33 ± 0.35 (n = 6)	3.04 ± 0.18 (n = 6)	5.33 ± 1.52 (n = 6)	20.92 ± 2.39 (n = 6)	2.79 ± 0.43 (n = 6)	15.42 ± 1.11 (n = 6)	101.96 ± 9.89 (n = 6)

Results in mg/L except where indicated.

[a] Sample collected during normal conditions.

[b] Sample collected during pumping of the septic tank overflow pump sump.

[c] TOC and DOC data reported by the NCCCWA were slightly higher than data reported by NEL.

[d] NEL provided total Kjeldahl nitrogen (TKN = organic nitrogen + TAN) and nitrate nitrogen (NO_3–N) analyses, whereas the NCCCWA provided total nitrogen (TN = organic nitrogen + -TAN + NO_3–N plus nitrite nitrogen [NO_2–N]) and total dissolved nitrogen (TDN = TAN + NO_3–N + NO_2–N). The TKN and TN data can be considered approximately equivalent because the TDN and TAN entering the fish hatchery were typically only 0.04 ± 0.01 and 0.11 ± 0.01 (TAN), respectively, and because no active nitrification occurred within the fish culture facility.

[e] NEL provided total phosphorus (TP) and dissolved phosphorus (DP), whereas the NCCCWA provided total reactive phosphorus (TRP). TRP accounts for some acid solubilization of particulate phosphorus, but does not include the complete particulate digestion process provided by the TP analysis. Therefore, TRP values would be expected to fall somewhere between DP and TP measurements, which was not the case when data from the two laboratories were compared. TRP data reported by the NCCCWA were consistently higher than TP data reported by NEL. It is not known which testing method should be considered more precise.

[f] There was a large discrepancy in TSS data reported by the two laboratories. Several additional influent water samples were analyzed for TSS by the environmental chemistry laboratory at the Freshwater Institute, and were found to be consistent with TSS results from NEL. The TSS data from NCCCWA were erroneously high, but are included to show trends.

Table 5
Average results, ±S.E., from metals analysis by the Cornell University Nutrient Analysis Lab (May–October)

Water quality parameter	Sample location	
	1	6a
Silver	0.06 ± 0.06 (n = 9)	0.00 ± 0.00 (n = 9)
Aluminum	120.0 ± 64.1	137.5 ± 68.8
Arsenic	4.31 ± 1.24	4.70 ± 1.26
Boron	3.48 ± 0.80	3.55 ± 0.65
Barium	0.55 ± 0.15	0.67 ± 0.18
Beryllium	37.60 ± 26.97	96.69 ± 54.54
Calcium	1698 ± 106	1972 ± 59
Cadmium	0.07 ± 0.02	0.11 ± 0.02
Cobalt	0.13 ± 0.06	0.23 ± 0.12
Chromium	1.56 ± 0.59	1.91 ± 0.78
Copper	1.15 ± 0.40	1.08 ± 0.42
Iron	2.09 ± 0.73	3.64 ± 1.38
Potassium	195.1 ± 25.1	311.0 ± 46.1
Lithium	3.06 ± 0.38 (n = 9)	3.53 ± 0.21 (n = 9)
Magnesium	432.6 ± 29.0	487.6 ± 9.8
Manganese	7.73 ± 2.90	2.10 ± 0.34
Molybdenum	1.05 ± 0.22	1.08 ± 0.22
Sodium	1483 ± 144	1718 ± 104
Nickel	0.68 ± 0.33	0.67 ± 0.34
Phosphorous	6.92 ± 1.24 (n = 9)	23.04 ± 9.26 (n = 9)
Lead	2.73 ± 1.42	2.79 ± 1.41
Sulfur	929.9 ± 65.5	1054 ± 43
Selenium	0.34 ± 0.15	0.73 ± 0.27
Silicon	151.2 ± 19.6	192.3 ± 26.0
Tin	0.01 ± 0.01 (n = 9)	0.00 ± 0.00 (n = 9)
Strontium	8.50 ± 0.61	9.65 ± 0.28
Titanium	0.35 ± 0.14	0.54 ± 0.18
Thallium	11.78 ± 4.66	12.47 ± 4.65
Vanadium	32.09 ± 26.44	39.48 ± 32.50
Zinc	1.99 ± 0.91	4.29 ± 2.25

Results in ppb and n = 12 except where indicated.

units to 9 ± 3 CFU/mL (Table 3 and Fig. 2) following influent UV disinfection. Liltved and Cripps (1999) reported a 5 $\log_{10}$ reduction in heterotrophic plate count with a UV dose of 22,000 μW/(s cm^2) when preceded with 50 μm filtration, and similar UV dosages have been reported to achieve the same and greater $\log_{10}$ reductions in *A. salmonicida* bacteria. Similarly, UV disinfection of the influent surface water supply at Green Lake NFH indicated a 99.3% reduction (i.e., greater than 2 $\log_{10}$ reduction) in six different types of bacteria commonly associated with fish diseases using an average UV dose of 28,400 μW/(s cm^2) (Cross and Peterson, 1987).

3.2. Effluent treatment at the wild fish-receiving building

During normal operation, TSS concentrations were below the detection limit (1 mg/L) before and after the microscreen drum filters treating the effluent from the receiving building. During events when the supernatant from the septic tank was pumped to the front of the microscreen drum filters, mean TSS concentrations entering and exiting the drum filter were 15 ± 3 and 9 ± 1 mg/L, respectively (Table 3). TSS data for individual sampling events are shown in Fig. 3. Also indicated in Fig. 3 are the TSS removal efficiencies across the microscreen drum filter for each sampling event during supernatant pumping. As expected, the TSS removal efficiency of the drum filter generally increased at higher influent TSS levels. Excluding the single event that showed an increase in TSS across the microscreen drum filter, the average TSS removal efficiency was 39% during supernatant pumping events (n = 5).

It is important to note the large difference in effluent TSS and TP levels that occur in the effluent from the receiving building between normal operation and supernatant pumping (Figs. 3 and 4). Average effluent TSS and TP levels during supernatant pumping events were 9 ± 1 and 0.86 ± 0.1 mg/L, respectively. These TSS and TP levels represent 817% and 4200% increases over normal operating levels, respectively. These phenomena can be attributed to microbial activity in the septic tank that causes leaching of phosphorus, nitrogen, and fine solid particles. This is strong evidence to adopt a permanent and effective solids management system when designing effluent treatment and solids management systems for hatcheries to reduce the discharge of phosphorus, nitrogen, and solids. One alternative to off-line settling and supernatant recirculation includes the use an inclined belt filter with coagulation and flocculation pre-treatment (Ebeling et al., 2006).

The average UV transmittance of water prior to UV treatment in the receiving building during normal system operation and supernatant pumping events was 93.0 and 82.3%, respectively, which are both above the 80% minimum design criteria for the units. However, five of 12 individual data points during the overflow pumping events were below the 80% design value. These low transmittance values did not cause adverse effects on the disinfection system because each UV irradiation unit is capable of treating a maximum flow of 1893 Lpm. The effluent from the building during the study period was only 114–227 Lpm due to low biomass in the building; approximately 10 times lower than the design capacity of the UV units.

Minimal total coliform bacteria were detected in the flow exiting the UV irradiation unit during normal operation and supernatant pumping events. No total

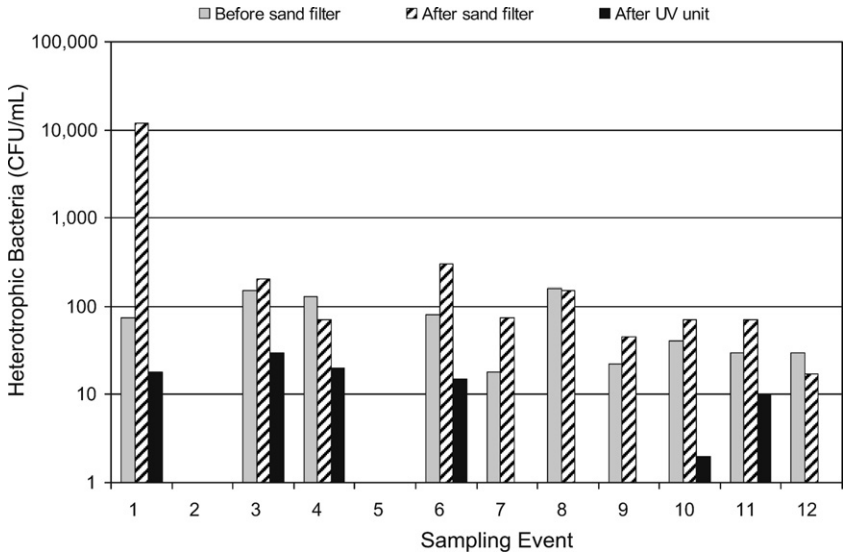

Fig. 2. Heterotrophic bacteria levels before the sand filters, after the sand filters, and after the UV units in the influent treatment building.

coliform bacteria were detected after the UV unit during normal operation for 8 of 11 sampling events, and no total coliform bacteria were detected after the UV unit during supernatant pumping for 9 of 11 sampling events. During normal operation and supernatant pumping events, the water entering the UV irradiation units contained a total heterotrophic bacteria concentration of $59{,}800 \pm 35{,}300$ CFU/mL and $590{,}000 \pm 428{,}000$ CFU/mL ($n = 10$), respectively. The UV irradiation units reduced the average total heterotrophic bacteria concentration to 8 ± 2 CFU/mL and 28 ± 15 CFU/mL, $\log_{10}$ reductions of 3.9 and 4.3, respectively, during normal operation and during supernatant pumping events. These trends are shown in Fig. 5 for individual sampling events.

Only very low levels of heterotrophic and total coliform bacteria remained post-UV irradiation in the effluent treatment process, and UV dosages to achieve a loss of infectivity of ISA virus have been reported to be 4000–10,000 μW/(s cm^2) (Torgersen, 1998). It is therefore reasonable to conclude that if ISA virus particles were present in the receiving building effluent, the

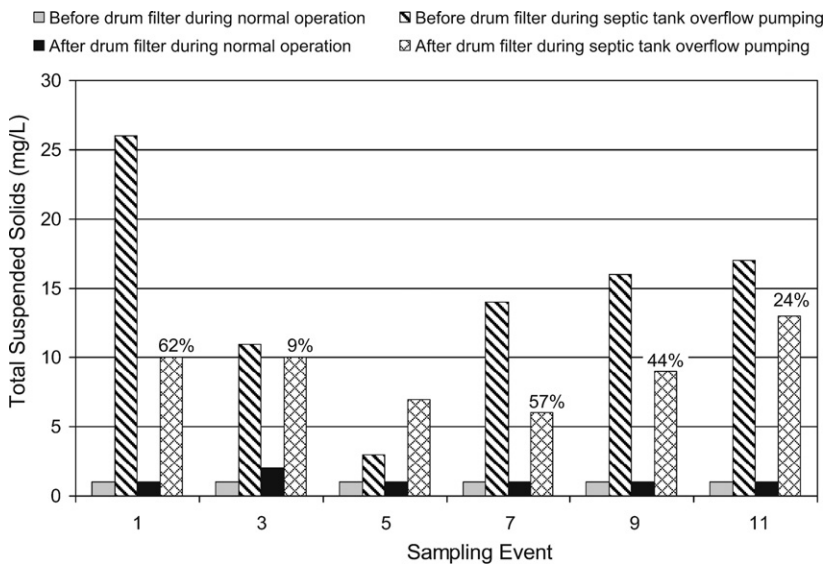

Fig. 3. TSS levels before and after the microscreen drum filter in the wild fish receiving building. Percent removal efficiencies are noted for overflow pumping events only.

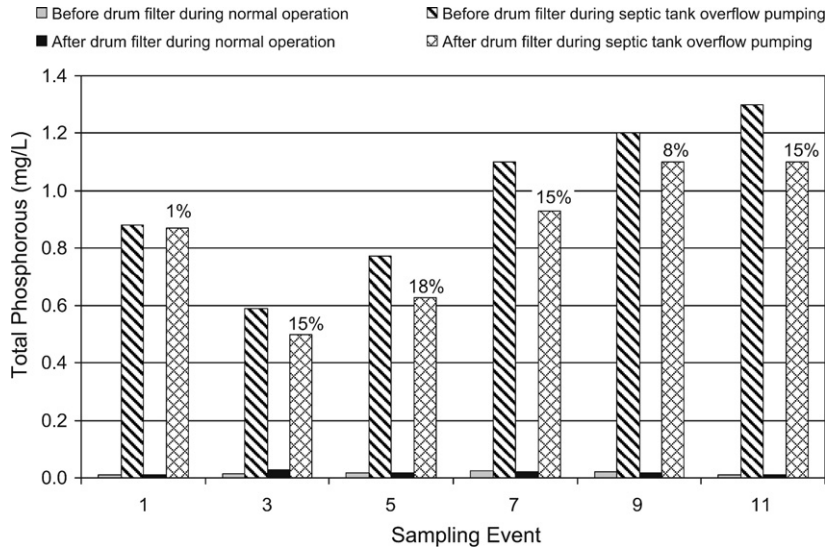

Fig. 4. TP levels before and after the microscreen drum filter in the wild fish receiving building. Percent removal efficiencies are noted for overflow pumping events only.

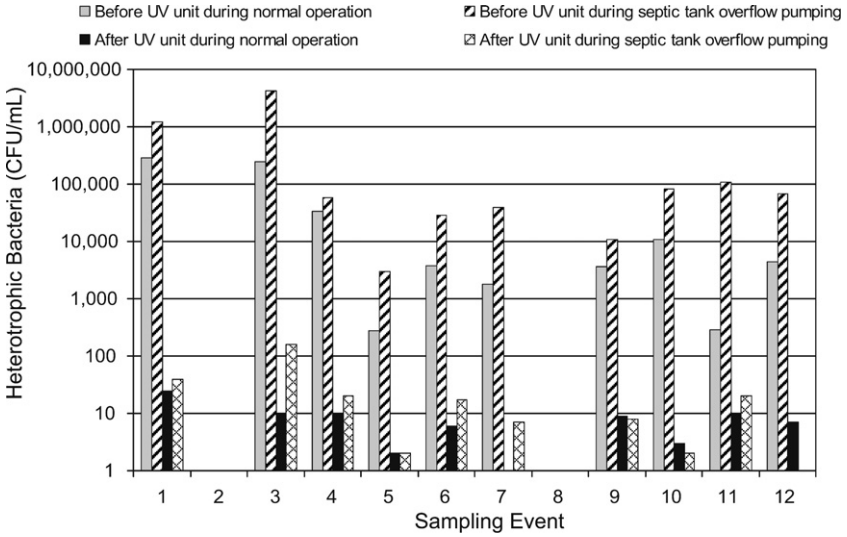

Fig. 5. Heterotrophic bacteria before and after the UV unit in the wild fish receiving building.

effluent treatment system would effectively reduce the pathogen levels by at least 4 $\log_{10}$ units or more, depending on the pathogen levels in the receiving building effluent.

4. Conclusions

The sand filtration and UV irradiation equipment in the influent treatment building were performing well, as indicated by the water quality data for TSS, UV transmittance, total coliforms, and heterotrophic bacteria. The influent treatment processes are capable of reducing heterotrophic bacteria levels by 2 $\log_{10}$ units or more, depending on the influent bacteria levels. It is reasonable to conclude that *A. salmonicida* present in the influent water supply is reduced the same amount. Overall, solids are excluded from the water exiting the influent treatment building and the water is considered to be nearly completely disinfected and of good quality for use in the hatchery's endangered Atlantic salmon program. Hatchery staff indicates that daily maintenance of the influent treatment system is minimal, and the hatchery has not experienced any disease problems attributable to the water supply.

The wild fish receiving building effluent microscreen filtration and UV irradiation equipment are also performing well, as indicated by the water quality data for TSS, UV transmittance, total coliforms, and heterotrophic bacteria. Only very low levels of heterotrophic bacteria and total coliforms remained post-UV irradiation in the effluent treatment process. The flowrates used in the wild fish-receiving building during the study period were lower than the system design flowrate. As a result, the actual UV dose of the disinfection units during the study period was greater than the 45,000 $\mu W/(s\ cm^2)$ design UV dose, which is above the 25,000 $\mu W/(s\ cm^2)$ minimum intensity approved to disinfect influent water supplies for hatcheries in Norway (Torgersen, 1997). The miscroscreen drum filter media excluded solids larger than 37 μm from the receiving building effluent and the flow was nearly completely disinfected, protecting the downstream hatchery watershed area. The performance evaluation of the effluent treatment system indicated the need for a more permanent solids management system to remove solids from drum filter backwash more rapidly and minimize nutrient leaching from captured biosolids.

The results of this case study indicate the efficacy of solids filtration followed by UV irradiation in real operational settings. Compared with the complexity of ozone systems, operation of the solids filtration and UV disinfection systems are straightforward and require minimal daily maintenance (Summerfelt, 2003). Of particular note is the proven effectiveness of the effluent treatment process: microscreen filtration followed by UV treatment. In cases where pathogen containment from aquaculture facilities is a potential issue, the treatment process studied here represents a viable solution. In future effluent treatment for pathogen containment applications, a solids management plan that reduces the impact of supernatant recirculation should be employed.

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